REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE 11/05/1999	3. REPORT TYPE AND DATES COVERED Final Report 10/01/98 - 9/30/99

4. TITLE AND SUBTITLE
Merging Disparate Data and Numerical Model Results for Dynamically Constrained Nowcasts

5. FUNDING NUMBERS
N/A

6. AUTHOR(S)
A. D. Kirwin, Jr., Principal Investigator
B. L. Lipphardt, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Old Dominion University Research Foundation
800 West 46th Street
Norfolk, VA 23508

8. PERFORMING ORGANIZATION REPORT NUMBER
283231

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
Ballston Centre Tower One
800 North Quincy Street, Arlington, VA 22217-5660

10. SPONSORING /MONITORING AGENCY REPORT NUMBER
N00014-99-1-0052

11. SUPPLEMENTARY NOTES
NONE

12a. DISTRIBUTION / AVAILABILITY STATEMENT
NONE

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

12b. DISTRIBUTION CODE
N68892

13. ABSTRACT (Maximum 200 words)

SEE ATTACHED

14. SUBJECT TERMS
SEE ATTACHED

15. NUMBER OF PAGES
5

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL

Merging Disparate Data and Numerical Model Results for Dynamically Constrained Nowcasts

A. D. Kirwan, Jr.
College of Marine Studies
University of Delaware
Newark, DE 19716
phone:(302) 831-2977   fax: (302) 831-6838   email: adk@udel.edu

B. L. Lipphardt, Jr.
College of Marine Studies
University of Delaware
Newark, DE 19716
phone: (302) 831-6836   fax: (302) 831-6838   email: brucel@udel.edu
Award #: N000149910052
http://newark.cms.udel.edu/~brucel/hrd.html

LONG-TERM GOALS

The long term goal of our research is to quantify submesoscale dynamical processes and understand their interactions with motions at larger scales. In particular, we focus on the following three areas:

- Use of high resolution disparate (HRD) data sets to develop dynamically consistent nowcasts of a flow field;

- Application of HRD observations to dynamical systems studies of the mixing properties of the surface flow field;

- Use of HRD surface observations to infer subsurface flow conditions.

OBJECTIVES

Our objective is to combine disparate surface current observations from sources like HF radar, Lagrangian drifters, passive remote sensing and ADCPs with open boundary flow information from any available source (numerical model, observations, climatology, etc.) to develop dynamically consistent nowcasts of the surface flow field. These nowcasts can then be analyzed using existing dynamical systems templates to study the mixing characteristics of the surface flow field.
Also, because our formulation is exactly three-dimensionally incompressible, the nowcast can be used to infer some features of the subsurface flow field and may be readily assimilated into a numerical model.

APPROACH

Our nowcast approach uses normal mode analysis (NMA), a spectral technique that is a generalization of a method first described by Rao and Schwab (1981) in an analysis of currents in Lake Ontario. The

NMA method involves projecting data onto numerically generated basis functions which consist of both vorticity and divergence modes. It is described by Eremeev *et al.* (1992a), and a variety of oceanographic applications are discussed in Eremeev *et al.* (1992b), Eremeev *et al.* (1995a,b), Lipphardt *et al.* (1997), and Cho *et al.* (1998). This approach has a number of attributes which make it well suited for rapid environmental assessment scenarios:

- Its spectral character readily admits data from disparate sources;

- Any arbitrarily shaped domain can be analyzed;

- The spatial basis set can be calculated to arbitrary accuracy independent of the data;

- Open boundary information from any source can be easily blended with observations;

- The nowcast velocity field is three-dimensionally incompressible.

WORK COMPLETED

We have completed work on our first proposed task: generating nowcasts from HF radar observations and numerical model open boundary flow. We applied the NMA method to HF radar data from Monterey Bay, supplied by Jeff Paduan at the Naval Postgraduate School. We were successful in both spatial and temporal filtering of the observations, and we developed a strategy for inserting supplemental numerical model velocities in regions where spatial gaps exist in the observations. The results of this Monterey Bay surface velocity analysis are described in a manuscript currently undergoing final review. More recently, we have begun analysis of a longer time series record for June-September 1999, and we have begun exploring the idea of using nested domains to produce open boundary velocities solely from observations on the domain interior.

Our second proposed task is the assessment of a numerical model of a semi-enclosed sea. For this task, we focus on a Gulf of Mexico model being run by Lakshmi Kantha's group at the University of Colorado. We have obtained model velocity data and drifter positions for the period June through December 1998. We expect to complete the assessment in the coming year.

We have also completed work on our third proposed task: nowcasts of Gulf of Mexico surface currents from disparate observations and a forecast model. A PhD student, LCDR William Schulz, successfully defended his dissertation in October 1999 (Schulz, 1999). His dissertation reports a series of nowcasts on the Louisiana-Texas shelf in the Gulf of Mexico that combine Lagrangian drifter observations, current meter observations, and results from the Navy's Modular Ocean Data Assimilation System (MODAS) model. His analysis highlighted some of the limitations of the MODAS model on the shelf and produced dynamically consistent convergence maps for the region. His dissertation represents a strong "proof of concept" for the application of the NMA method to an REA situation.

RESULTS

Our development of the NMA method has progressed to the point where we can routinely nowcast the surface velocity, vorticity, and divergence fields using HRD data for domains with large open boundary

segments. An example is shown in figure 1, which compares a 100 mode and a 12 mode nowcast of surface velocity in Monterey Bay. The HF radar observed velocity is shown in the upper panel. The lower two panels show the difference between the observed velocities and the two nowcasts. Spatial filtering with NMA is an important tool for reducing noise apparent in the observations.

Also, during this performance period a collaborative effort with Steve Wiggins and Chad Coulliette at Caltech has matured into a new task area for this effort. The Caltech group is interested in applying the latest generation of dynamical systems templates to the study of mixing processes in a coastal ocean area. Our surface velocity nowcasts in Monterey Bay are ideally suited for the testing and further development of their dynamical systems tools. Early results of their mixing analysis are very encouraging.

LCDR Schulz applied the NMA method to blend both Lagrangian drifter velocities and current meter velocities with the Navy's MODAS model to produce nowcasts of the surface velocity field on the Louisiana-Texas shelf during 1993 and 1994. His analysis revealed some interesting spectral properties apparent in the observations, and produced nowcasts that consistently agreed better with the observations than the MODAS model did. He approached the analysis as if it were a rapid environmental assessment problem, and demonstrated the utility of the NMA method for producing results quickly. In addition, he produced a time series of convergence maps on the shelf and addressed the question of how an operator might select the NMA modes to be used for such a near real time nowcast.
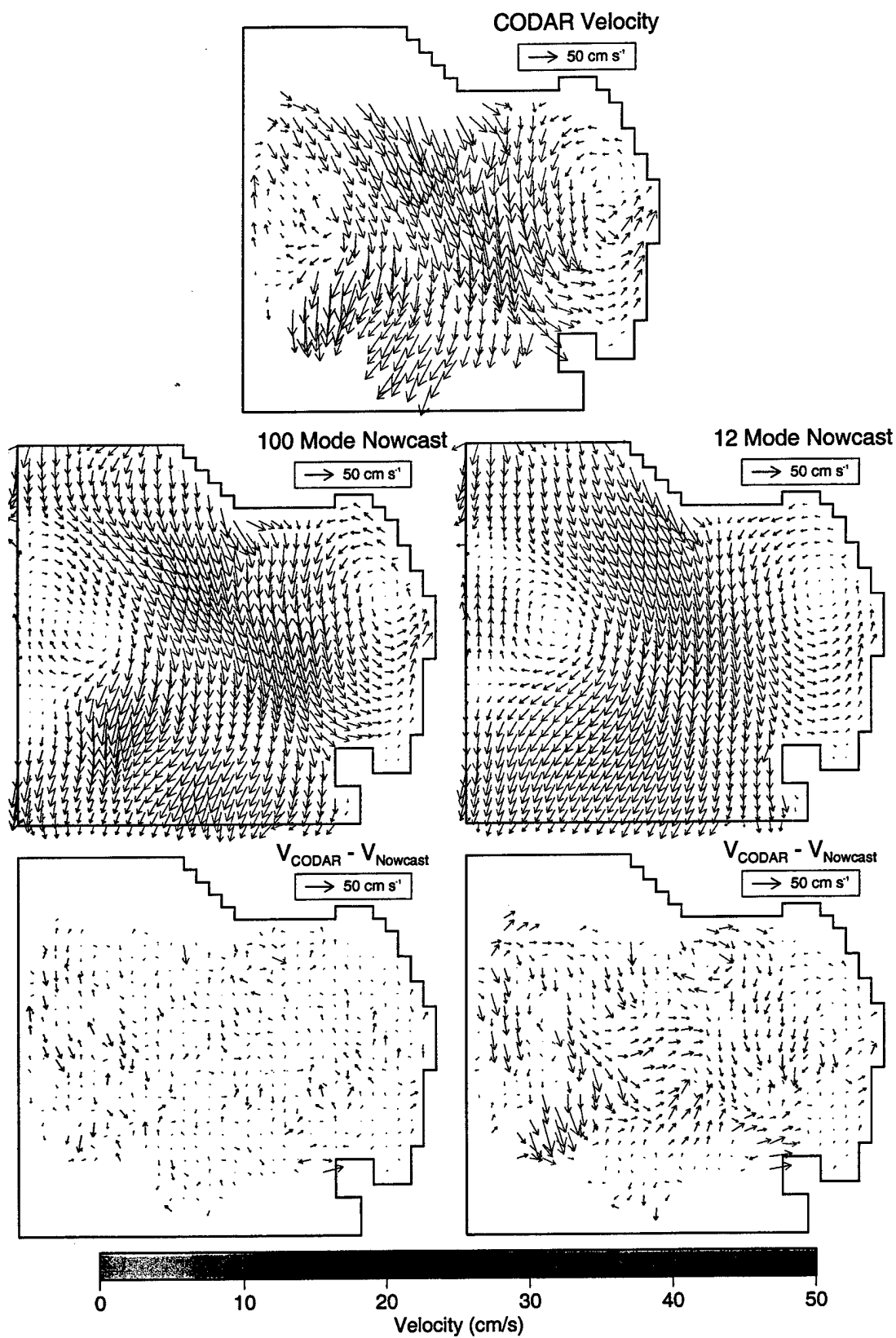
IMPACT/APPLICATIONS

We are continuing to demonstrate the utility of the NMA method as a tool for blending HRD data in a dynamically consistent way. It is applicable to any data and any grid at any resolution, it ensures three dimensional incompressibility and it naturally incorporates traditional boundary conditions. LCDR Schulz's work demonstrates one application to an REA analysis situation.

TRANSITIONS

LCDR Schulz's work included model results from the Naval Research Lab's Ocean Dynamics and Prediction Branch (Stennis Space Center - NRLSSC) 1/16 degree model of the Gulf of Mexico. His analysis of the Louisiana-Texas shelf represents a first step toward transitioning the NMA method to operational use as a REA tool.

RELATED PROJECTS

An ONR DRI entitled *Enhanced Ocean Predictability Through Optimal Observing Strategies* provides us with additional support to study the dynamical systems characteristics of ocean flows and to develop optimal sampling strategies for these flows. As part of this work, we have used the NMA method to study sampling strategies for a basin scale model of a double gyre. This work has been documented in a manuscript that is currently under review.

CODAR Velocity

$\longrightarrow$ 50 cm s^{-1}

100 Mode Nowcast

$\longrightarrow$ 50 cm s^{-1}

12 Mode Nowcast

$\longrightarrow$ 50 cm s^{-1}

$V_{CODAR} - V_{Nowcast}$

$\longrightarrow$ 50 cm s^{-1}

$V_{CODAR} - V_{Nowcast}$

$\longrightarrow$ 50 cm s^{-1}

0   10   20   30   40   50

Velocity (cm/s)

1. Comparison of 100 mode and 12 mode surface velocity nowcasts in Monterey Bay for 0100 GMT, 9 August 1994.

As part of our ONR sponsored work we continue to collaborate with scientists from Caltech, the Naval Postgraduate School, the University of Colorado, and Ocean Physics Research and Development to analyze HF radar and model data, and to study mixing processes in the coastal ocean.

REFERENCES

Cho, K., R. O. Ried, and W. D. Nowlin, Jr. Objectively mapped stream function fields on the Texas-Louisiana shelf based on 32 months of moored current meter data. *J. Geophys. Res., 103*, 10,377-10,390, 1998.

Eremeev, V. N., L. M. Ivanov, and A. D. Kirwan, Jr., Reconstruction of oceanic flow characteristics from quasi-Lagrangian data 1: Approach and mathematical methods, *J. Geophys. Res., 97*, 9733-9742, 1992a.

Eremeev, V. N., L. M. Ivanov, and A. D. Kirwan, Jr., Reconstruction of oceanic flow characteristics from quasi-Lagrangian data 2: Characteristics of the large-scale circulation in the Black Sea, *J. Geophys. Res., 97*, 9743-9753, 1992b.

Eremeev, V. N., L. M. Ivanov, A. D. Kirwan, Jr, and T. M. Margolina. Amount of ^{137}Cs and ^{134}Cs radionuclides in the Black Sea produced by the Chernobyl disaster. *J. Environ. Radiol., 27*, 49-63, 1995a.

Eremeev, V. N., L. M. Ivanov, A. D. Kirwan, Jr., and T. M. Margolina. Analysis of the Cesium pollution in the Black Sea by regularization methods. *Mar. Poll. Bull., 30*, 460-462, 1995b.

Lipphardt, B. L., Jr., A. D. Kirwan, Jr., C. E. Grosch, L. M. Ivanov and J. K. Lewis. Merging disparate oceanographic data, In *Proceedings of the SACLANT Rapid Environmental Assessment Conference*, Lerici, Italy, March 1997.

Rao, D. B. and D. J. Schwab. A method of objective analysis for currents in a lake with application to Lake Ontario. *J. Phys. Oceanogr., 11*, 739-750. 1981.

Schulz, W.J., Jr. Ocean surface maps from blending disparate data through normal mode analysis. *Ph.D. dissertation*, Old Dominion University, Norfolk, Virginia. 102 pp. 1999.

PUBLICATIONS

Kirwan, A. D., Jr. and B. L. Lipphardt, Jr. Integrable unsteady motion with an application to ocean eddies. *Nonlinear Proc. in Geophys.* 5: 145-151, 1998.

Lipphardt, B. L., Jr., A. D. Kirwan, Jr., C. E. Grosch, J. K. Lewis, and J. D. Paduan. Blending HF radar and model velocities in Monterey Bay through normal mode analysis. *J. Geophys. Res.,* submitted, 1999.

Schulz, W.J., Jr. Ocean surface maps from blending disparate data through normal mode analysis. *Ph.D. dissertation*, Old Dominion University, Norfolk, Virginia. 102 pp. 1999.

DISTRIBUTION STATEMENT AUTHORIZATION RECORD

Title: *Merging Disparate Data and Numerical Model Results for Dynamically Constrained Nowcasts*

Authorizing Official: *Scott Sandgathe*

Agency: *ONR* Ph. No. *(703) 696-0802*

☐ Internet Document: URL: _____
(DTIC-OCA Use Only)

Distribution Statement: (Authorized by the source above.)

☒ **A:** Approved for public release, distribution unlimited.

☐ **B:** U. S. Government agencies only. (Fill in reason and date applied). Other requests shall be referred to (Insert controlling office).

☐ **C:** U. S. Government agencies and their contractors. (Fill in reason and date applied). Other requests shall be referred to (Insert controlling office).

☐ **D:** DoD and DoD contractors only. (Fill in reason and date applied). Other requests shall be referred to (Insert controlling office).

☐ **E:** DoD components only. (Fill in reason and date applied). Other requests shall be referred to (Insert controlling office).

☐ **F:** Further dissemination only as directed by (Insert controlling DoD office and date), or higher authority.

☐ **X:** U. S. Government agencies and private individuals or enterprises eligible to obtain export-controlled technical data in accordance with DoD Directive 5230.25.

NOTES: *Missing distribution statement*

_____

_____

_____

_____

J. Keith   *16 Nov 99*
DTIC Point of Contact   Date